



## SOLAR SAIL INTERACTIONS



# *Charged Particle Effects on Solar Sails An Overview*

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# AGENDA

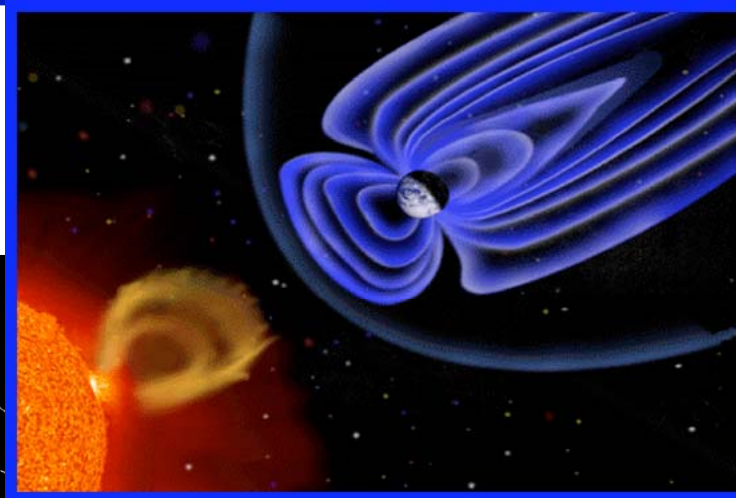
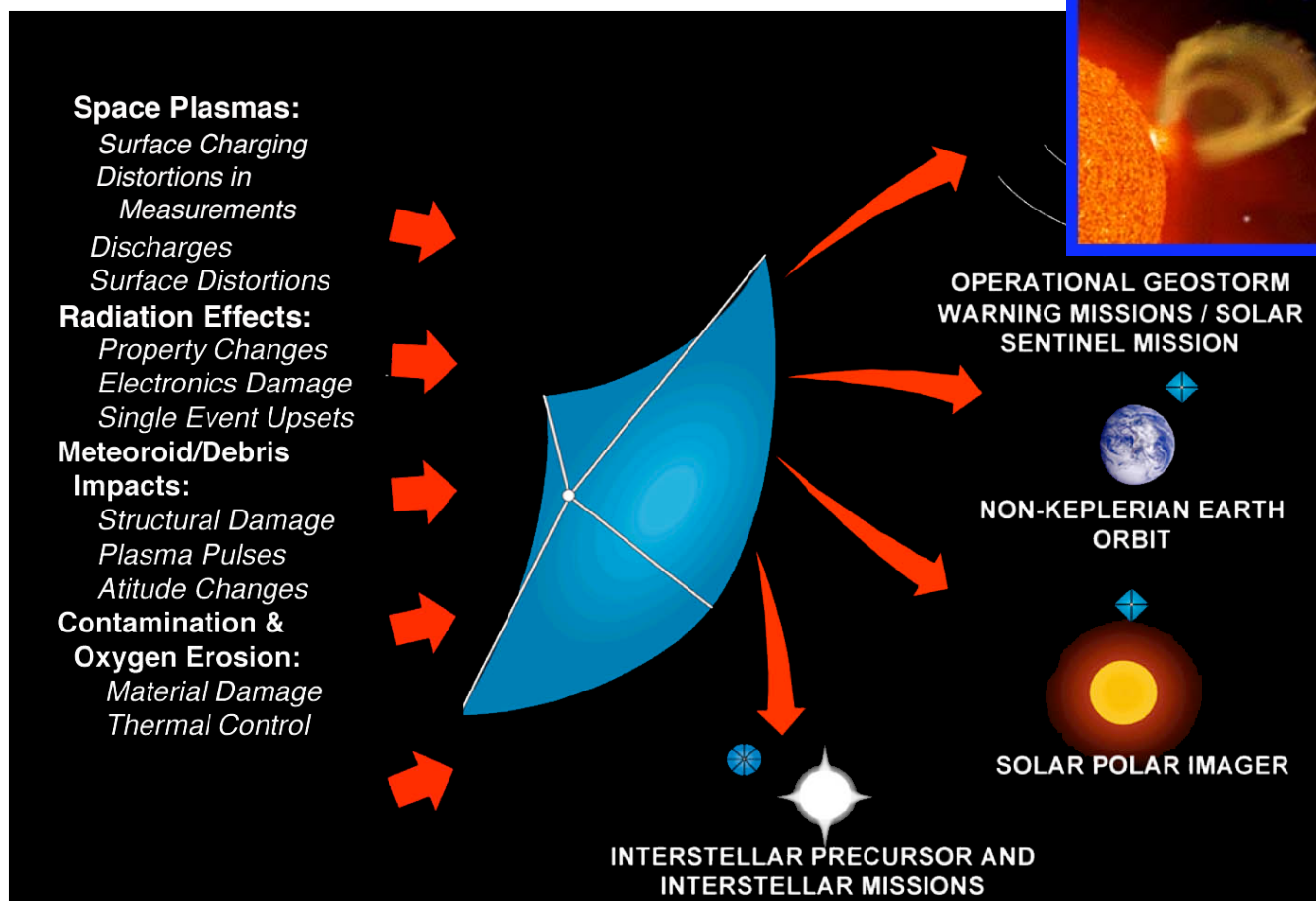
- Overview
  - Why do We Care About the Environment?
- Charging Environment Definition
  - What is the Ambient Environment Like?
- Surface Charging
  - How do Sails Charge in Space?
- Plasma Flow Effects
  - What does This Mean for Experiments?
- Summary
  - Where do We Go Next?

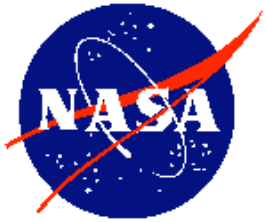


## SOLAR SAIL INTERACTIONS



# Why do We Care About the Environment?



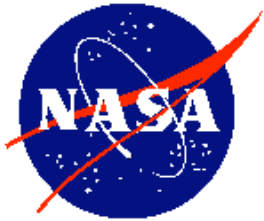


## ***What do We Need to Know?***

**1#--We require modeling and experimental validation of solar sail charging in the space environment:**

- a. Need to define representative charged particle environments in the solar wind and geosynchronous orbit.***
- b. Need to develop surface and internal charging models of solar sails***
- c. Need to conduct experimental testing of candidate solar sail materials in the specified environments***
- d. Need to develop an integrated solar sail charging model for comparing sail designs and doing design trades***

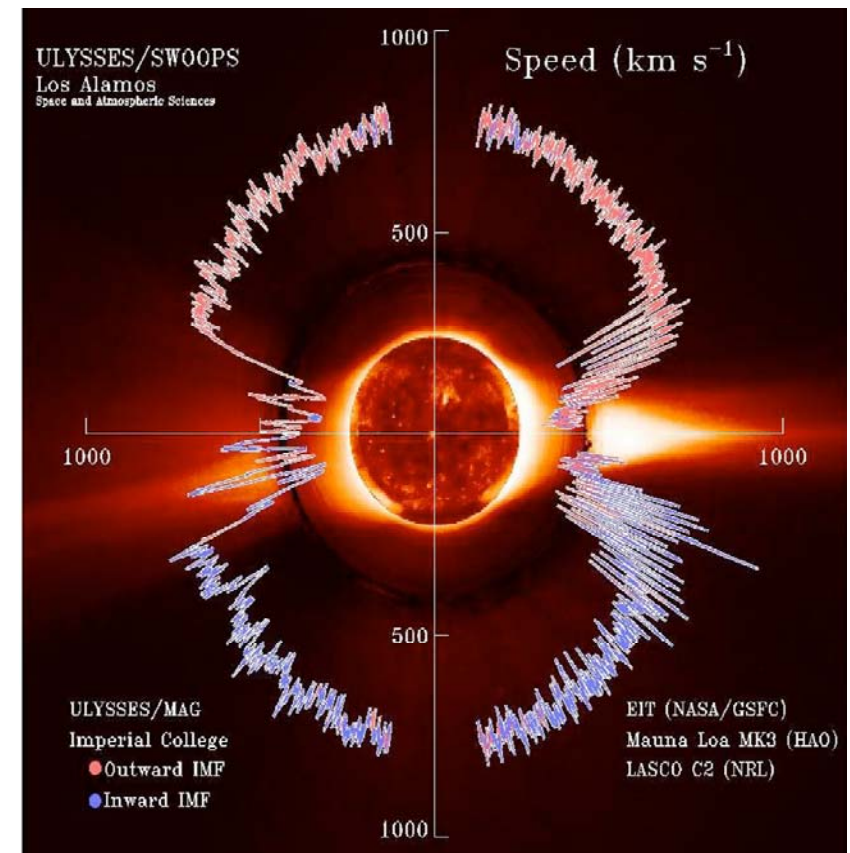
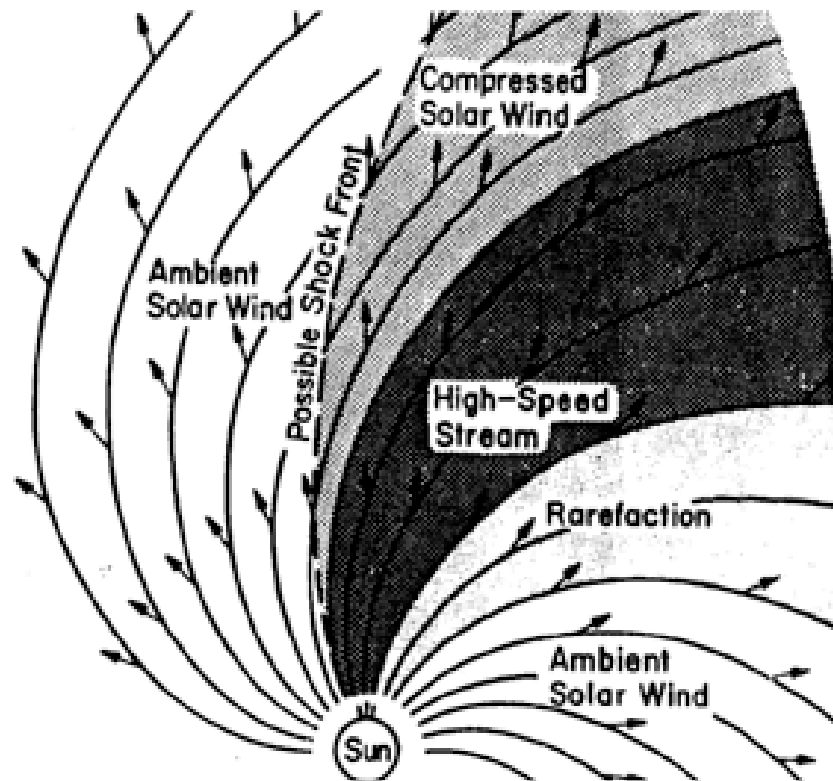




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# *The Solar Wind Environment*

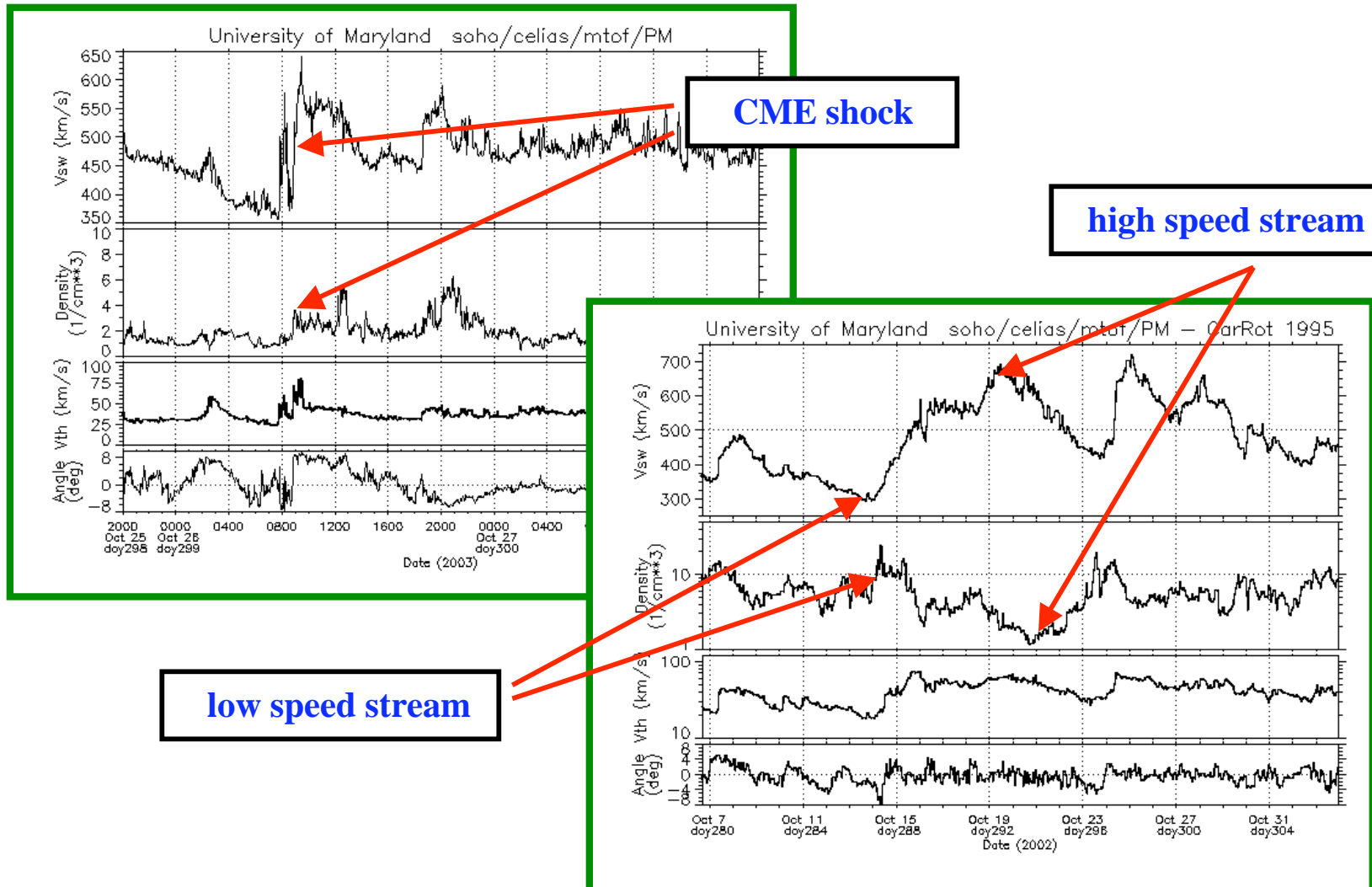


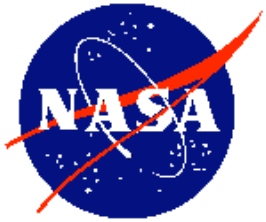


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# Solar Wind Extreme Environments





## *Model Assumptions*

- **“Nominal” Solar Wind:**

$$v_{sw} \sim 400 \text{ km/s}$$

$$T_i \sim 10 \text{ eV}$$

$$B_o \sim 10^{-4} \text{ Gauss}$$

$$n_{sw} \sim 3.5 \text{ cm}^{-3}$$

$$T_e \sim 40 \text{ eV}$$

- **Plasma Parameters:**

$$\lambda_D \sim 25 \text{ m};$$

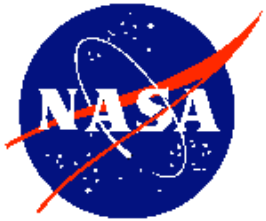
$$v_{ti} \sim 30 \text{ km/s}$$

$$\Omega_i \sim 1 \text{ rad/s}$$

$$v_{te} \sim 2.65 \times 10^3 \text{ km/s}$$

$$c_s = (T_e/m_p)^{1/2} \sim 62 \text{ km/s}$$

$$\Omega_e \sim 1.8 \times 10^3 \text{ rad/s}$$



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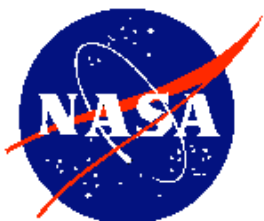


# *Worst Case Geosynchronous Environments\**

	ATS-6	Deutsch	SCATHA	Mullen1	SCATHA	Mullen2
	Electrons	Ions	Electrons	Ions	Electrons	Ions
Density, $\text{cm}^{-3}$	1.22	0.245	0.9	2.3	3	3
Tavg, keV	16	28.4	7.7	5.5	5.33	8.22
Trms, keV	16.1	29.5	9	14	7.33	11.8
N1, $\text{cm}^{-3}$	0	0.00882	0.2	1.3	1	1
T1, eV	0	111	400	300	600	350
N2, $\text{cm}^{-3}$	1.22	0.236	1.45	0.95	1.65	1.65
T2, keV	16	29.5	24.4	27.1	25.5	25.1

**\*From NASA TP-2361, 1984**

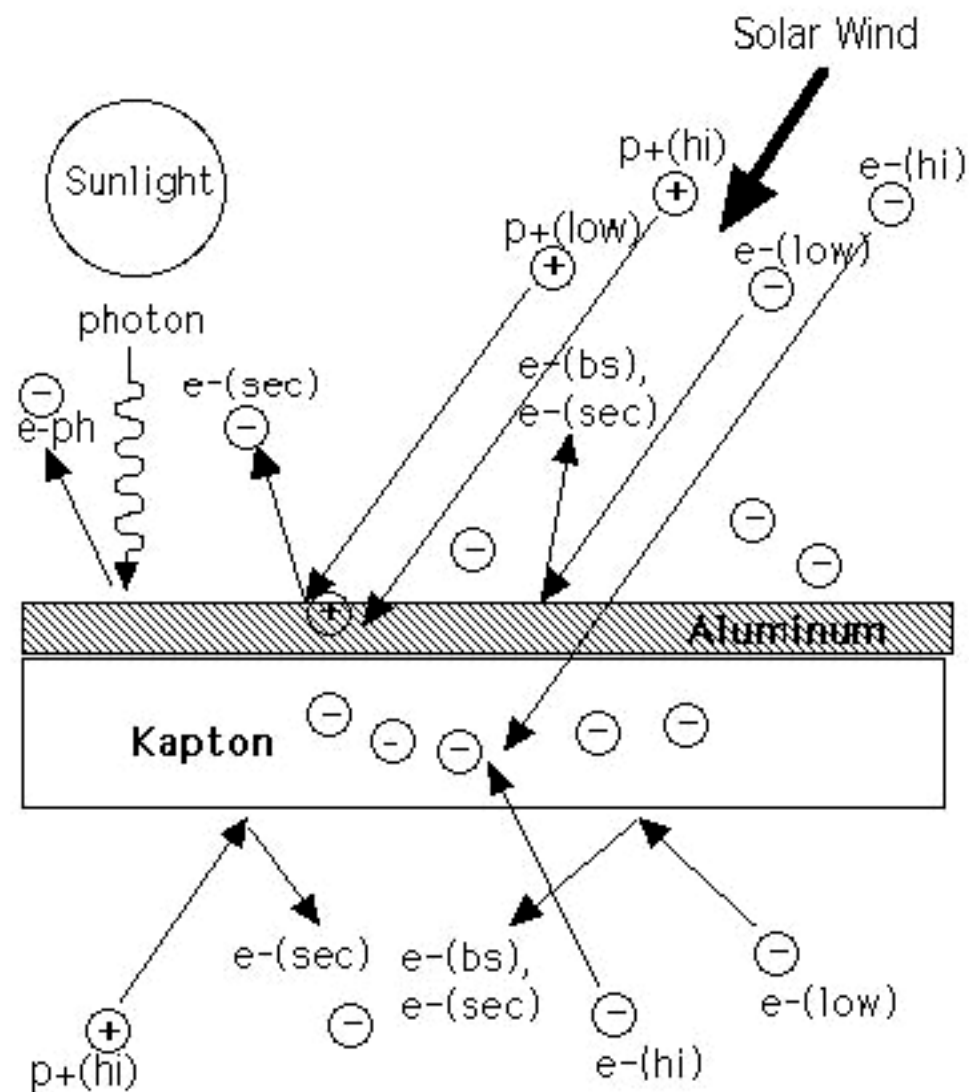




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### *Current Balance on the Sail Membrane*



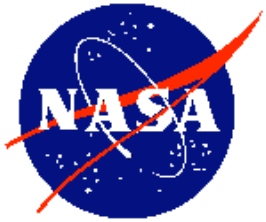


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# *Test Environments and Surface Potentials*

PLASMA ENVIRONMENT:	0.5 AU	1.0 AU	Geosynch
RE1 (cm <sup>-3</sup> ):	50	3.5	1.2
TE1 (eV):	65	40	24400
RI1 (cm <sup>-3</sup> ):	50	3.5	0.88
TI1 (eV):	40	10	27000
RE2 (cm <sup>-3</sup> ):			0.2
TE2 (eV):			400
RI2 (cm <sup>-3</sup> ):			1.3
TI2 (eV):			300
CPH (nAmps/cm <sup>-2</sup> ):	8	2	2
SAT VELOCITY (km/s):	500	400	3
POTENTIALS:	0.5 AU	1.0 AU	Geosynch
Shadowed (insulator):	-39.06	-45.7	-8144.5
Sunlight (conductive):	6.01	9.23	0.79

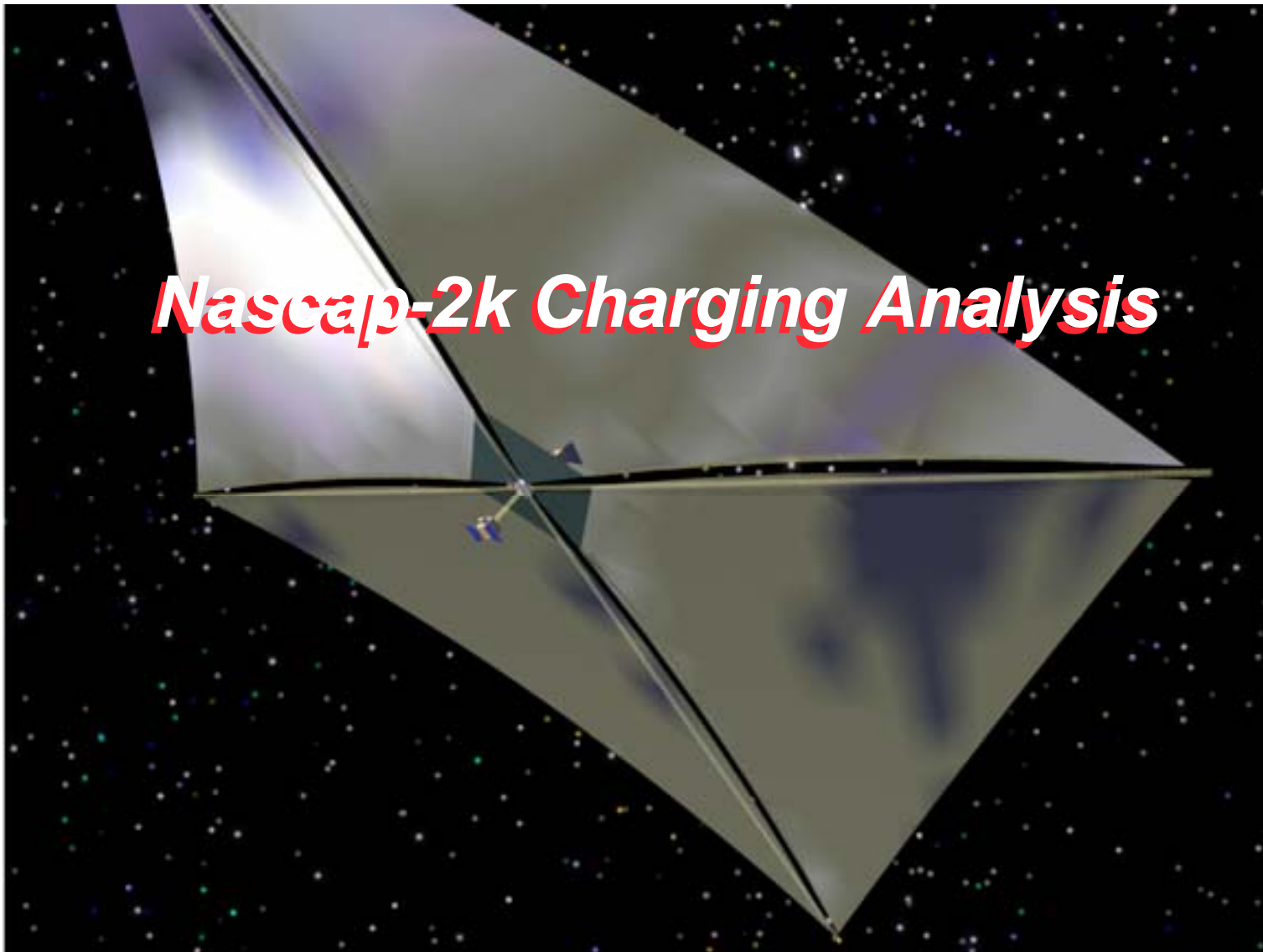


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JPL



# *Nascap-2k Charging Analysis*

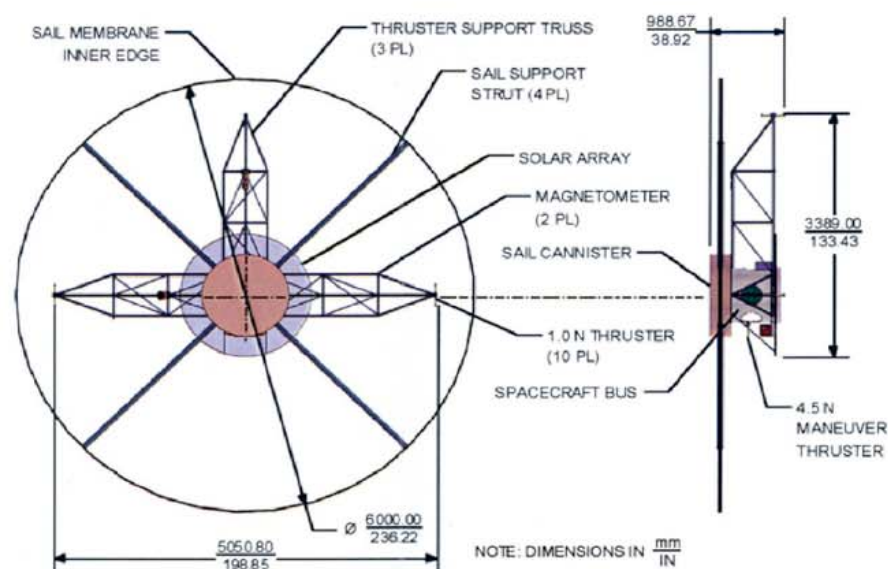
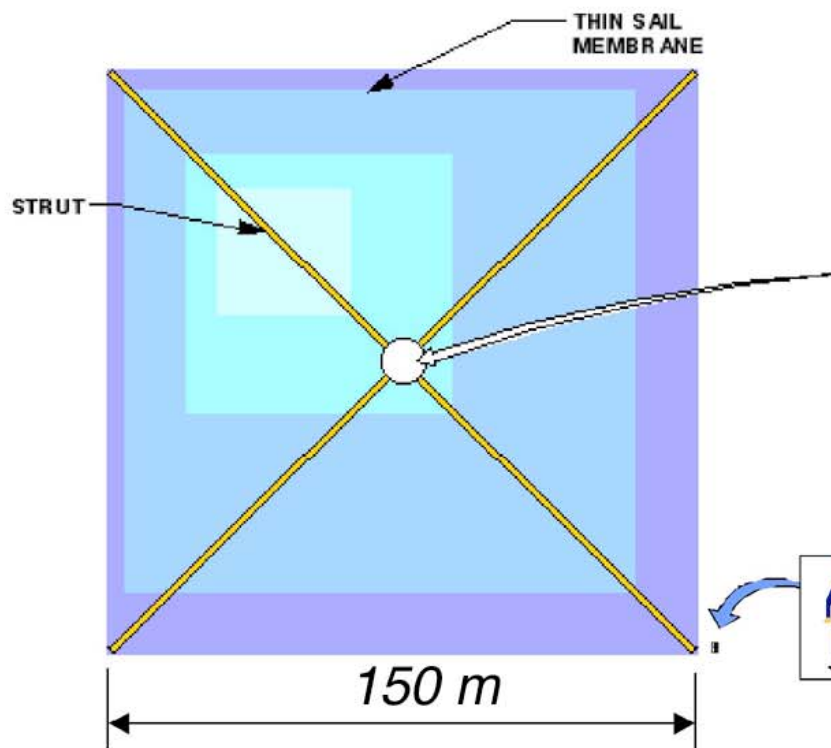


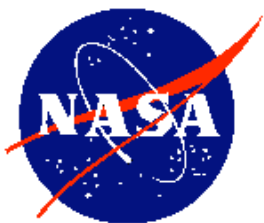


## SOLAR SAIL INTERACTIONS

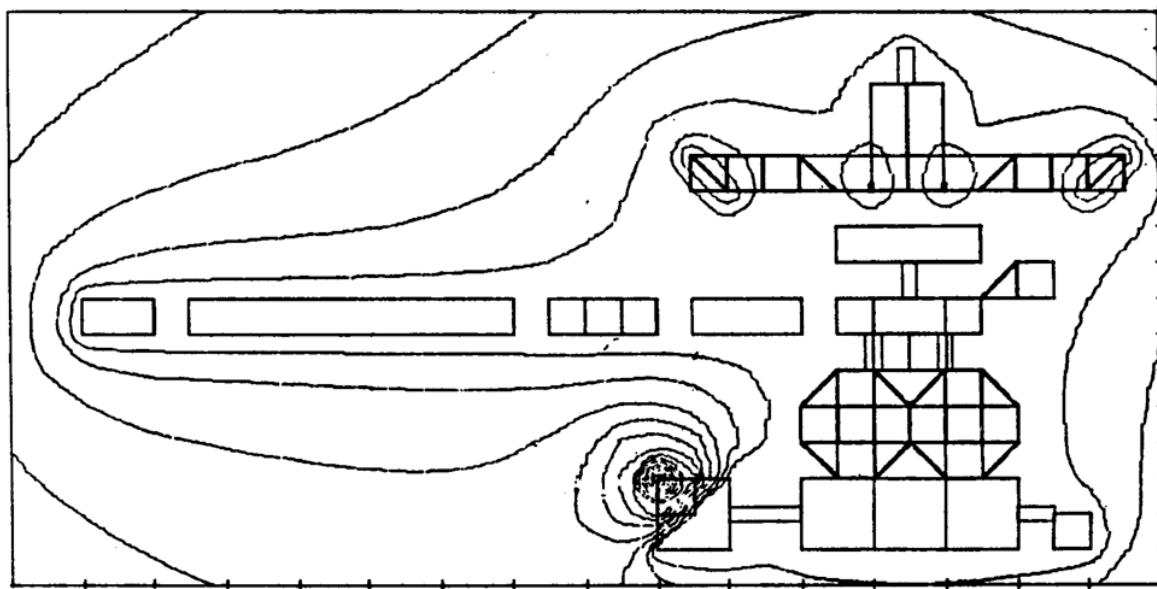


# 150m x 150m Generic Sail Design





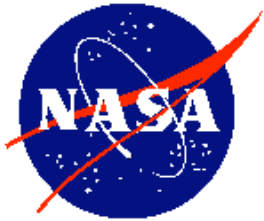
# ***SAMPLE NASCAP POTENTIAL CONTOURS***



GALILEO POTENTIAL CONTOURS

**“POTENTIAL CONTOUR” MODEL!**

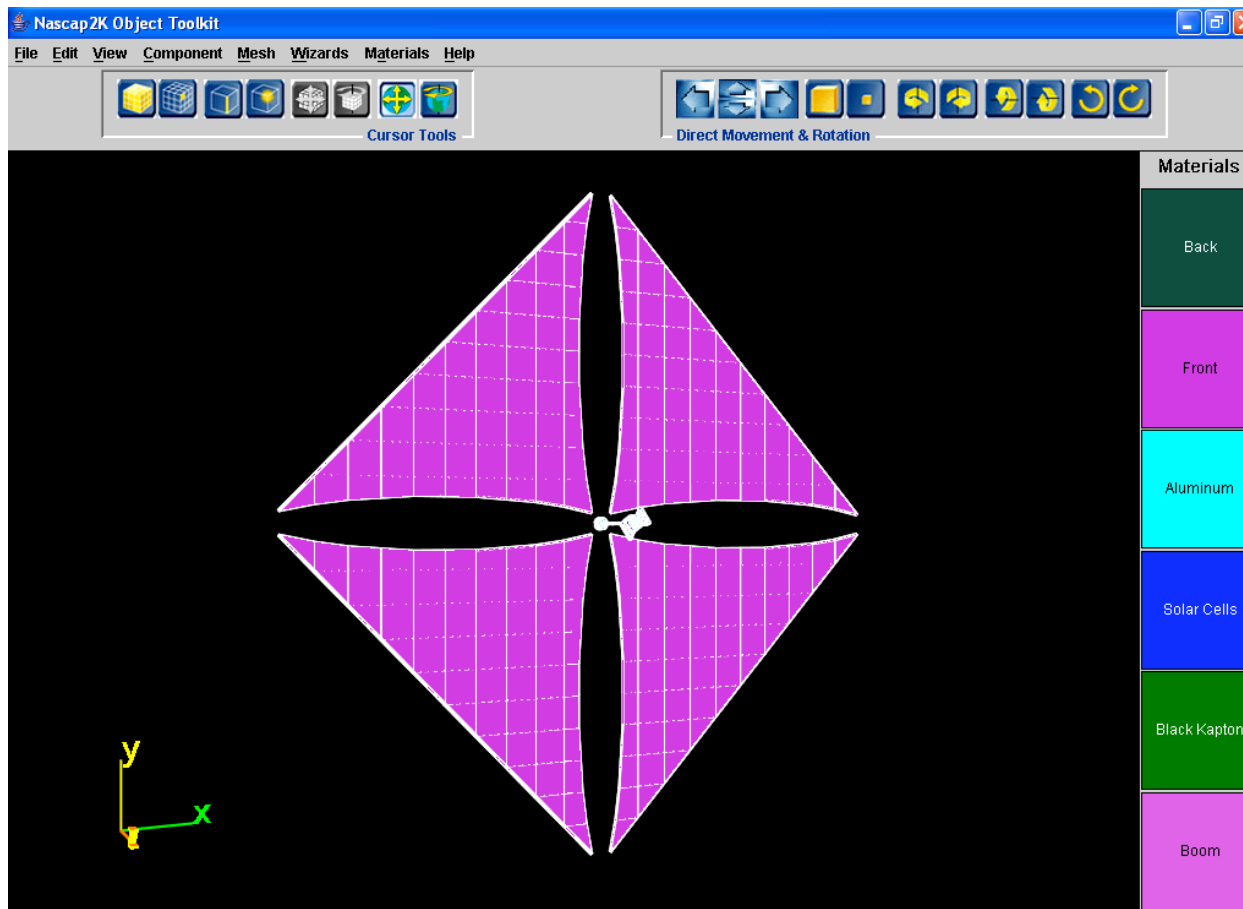




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# 150 m Solar Sail Material Model



### Solar Sail:

Front – Aluminum

Back - Kapton

Hypotenuse = 150 m

### Spacecraft body:

Aluminum

### Solar Arrays front

– Solar Cells

### Solar Array back

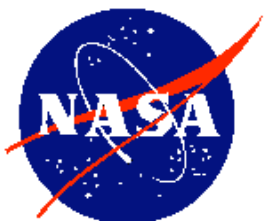
– Black Kapton

### Boom connecting

### Spacecraft

and Solar Array craft

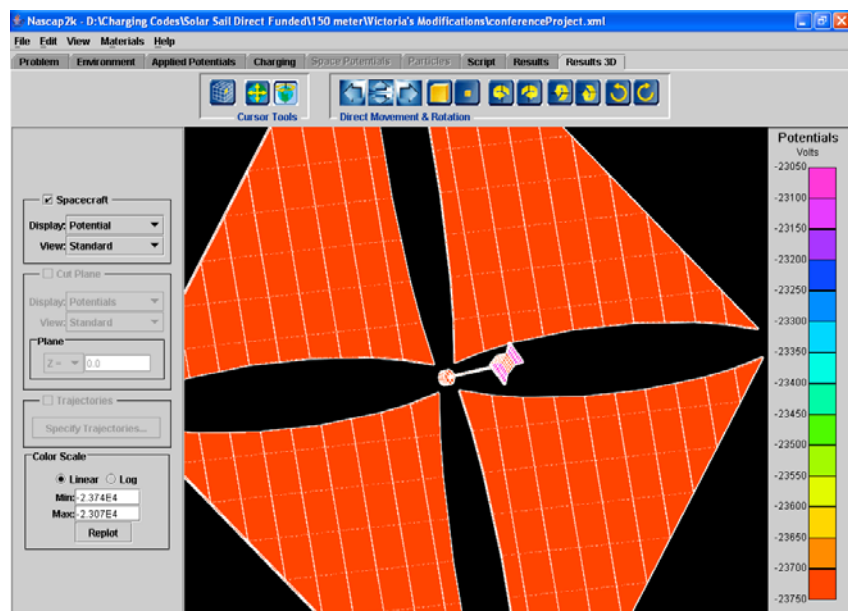
- Kapton



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# GEO Charging Analysis



## A. ECLIPSE

### Environment:

$$N_e = 1.12 \text{ cm}^{-3}$$

$$T_e = 12 \text{ keV}$$

$$N_i = .236 \text{ cm}^{-3}$$

$$T_i = 29.5 \text{ keV}$$

### A. Eclipse:

$$\text{Boom: } -23.72 \text{ kV}$$

$$\text{Sail front: } -23.74 \text{ kV}$$

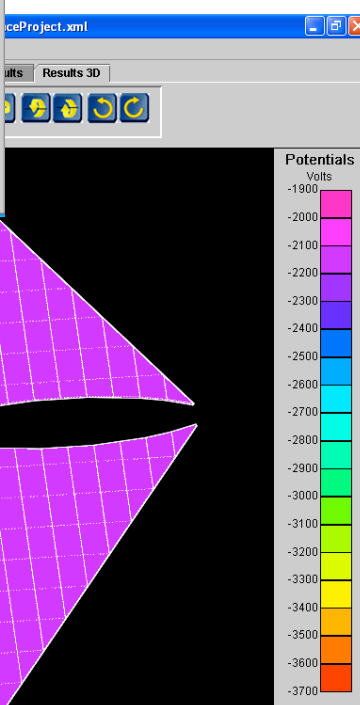
$$\text{Sail back: } -23.71 \text{ kV}$$

$$\text{Spacecraft: } -23.74 \text{ kV}$$

$$\text{Solar Array front: } -23.09 \text{ kV}$$

$$\text{Solar Array back: } -23.74 \text{ kV}$$

$$\text{Differential } \Phi: \sim 650 \text{ V}$$



## B. SUN

### B. Sunlit in the +z direction

$$\text{Boom: } -3636 \text{ V}$$

$$\text{Sail front: } -2131 \text{ V}$$

$$\text{Sail back: } -3636 \text{ V}$$

$$\text{Spacecraft: } -2131 \text{ V}$$

$$\text{Solar Array front: } -2116 \text{ V}$$

$$\text{Solar Array back: } -2131 \text{ V}$$

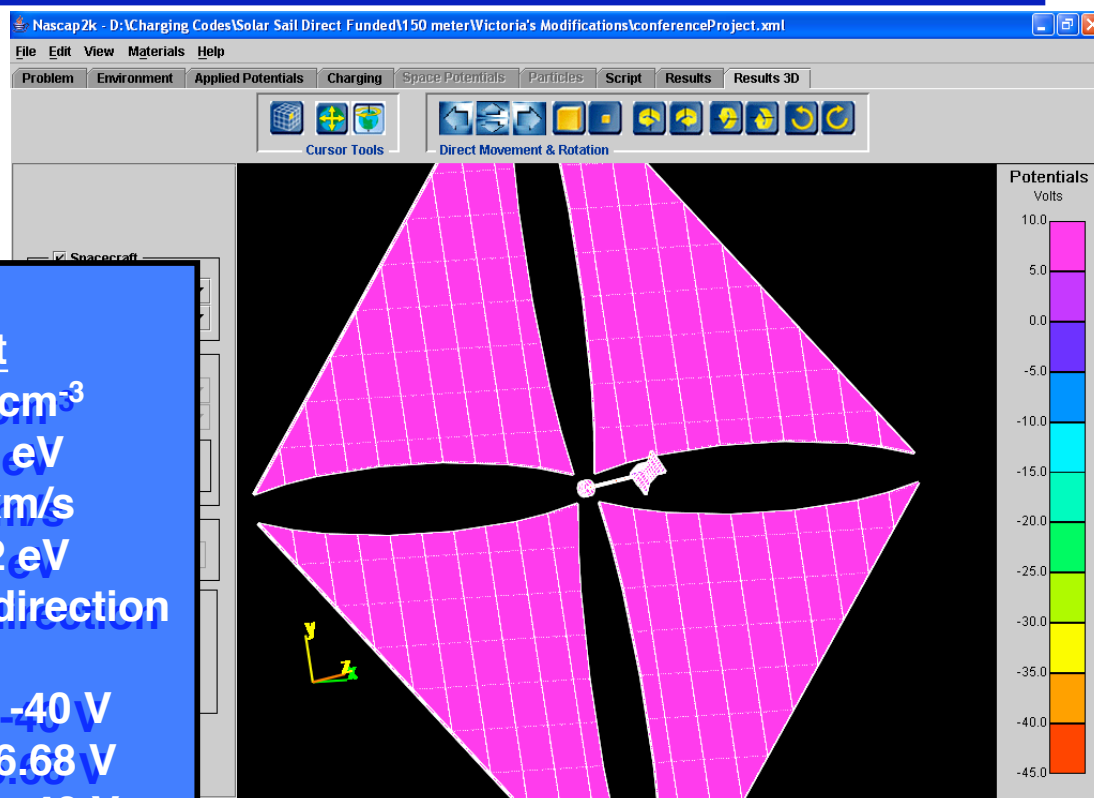
$$\text{Differential } \Phi: \sim 1500 \text{ V}$$



## SOLAR SAIL INTERACTIONS



# Solar Wind Charging Analysis



**0.5 AU**

### Environment

$$N_e = 17.08 \text{ cm}^{-3}$$

$$T_e = 10.6 \text{ eV}$$

$$v_i = 702 \text{ km/s}$$

$$E_i = 2573 \text{ eV}$$

sun in +z direction

$$\text{Boom: } -43.11 \text{ V}$$

$$\text{Sail front: } 7.8 \text{ V}$$

$$\text{Sail back: } -43.11 \text{ V}$$

$$\text{Spacecraft: } 7.8 \text{ V}$$

Solar Array:

$$\text{front: } 2.8 \text{ to } 7.8 \text{ V}$$

$$\text{back: } 7.8 \text{ V}$$

$$\text{Differential } \Phi: \sim 50 \text{ V}$$

**1 AU**

### Environment

$$N_e = 12.8 \text{ cm}^{-3}$$

$$T_e = 11.13 \text{ eV}$$

$$v_i = 327 \text{ km/s}$$

$$E_i = 558.2 \text{ eV}$$

sun in +z direction

$$\text{Boom: } -40 \text{ V}$$

$$\text{Sail front: } 6.68 \text{ V}$$

$$\text{Sail back: } -40 \text{ V}$$

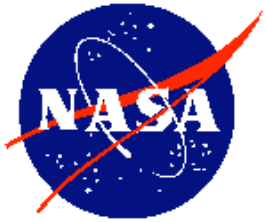
$$\text{Spacecraft: } 6.68 \text{ V}$$

Solar Array:

$$\text{front: } 6.68 \text{ to } -3 \text{ V}$$

$$\text{back: } 6.68 \text{ V}$$

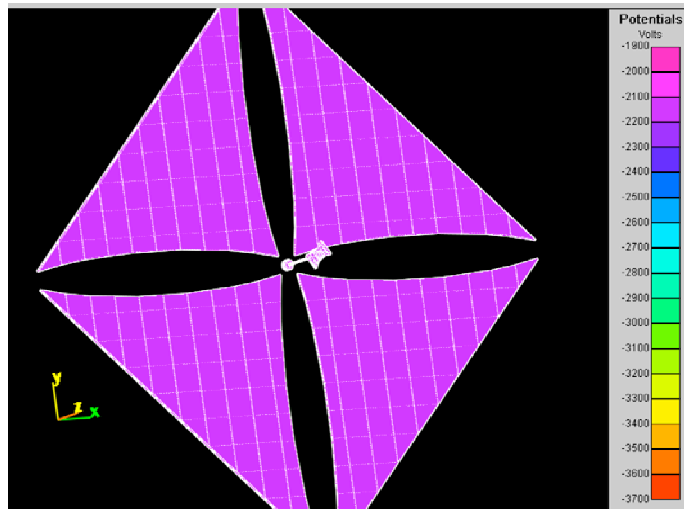
$$\text{Differential } \Phi: \sim 47 \text{ V}$$



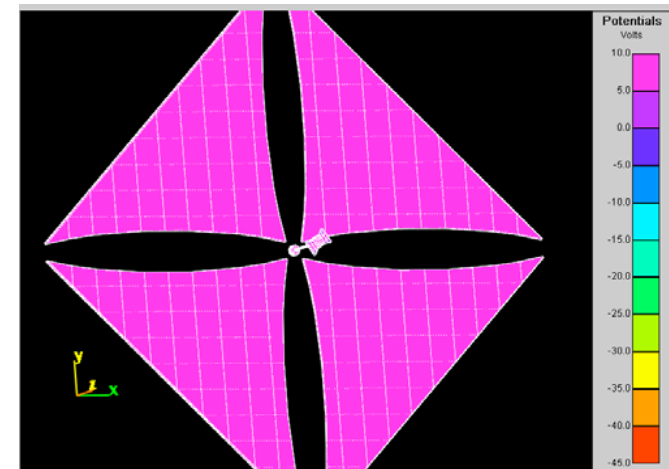
## SOLAR SAIL INTERACTIONS



# ***NASCAP-2K CHARGE MODELING***

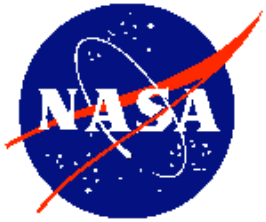


**A**

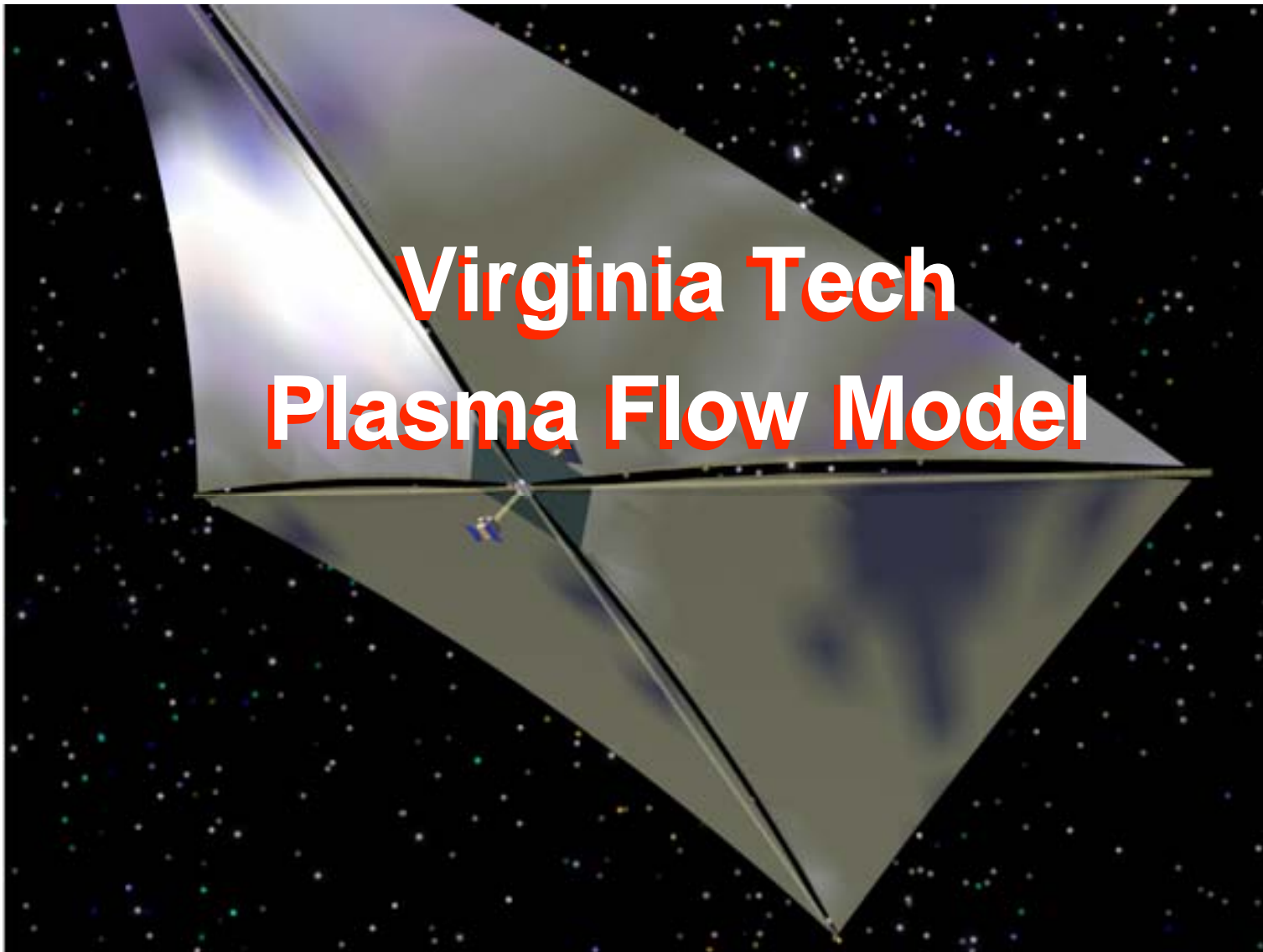


**B**

- A) Geostationary orbit yields extreme differential potentials of -2.1 kV on the illuminated surface (shown) and -3.6 kV on the back surface.**
- B) Solar wind (1 AU) environments yield more moderate potentials of +6.7 V on the illuminated surface (shown) and -40 V on the back surface.**



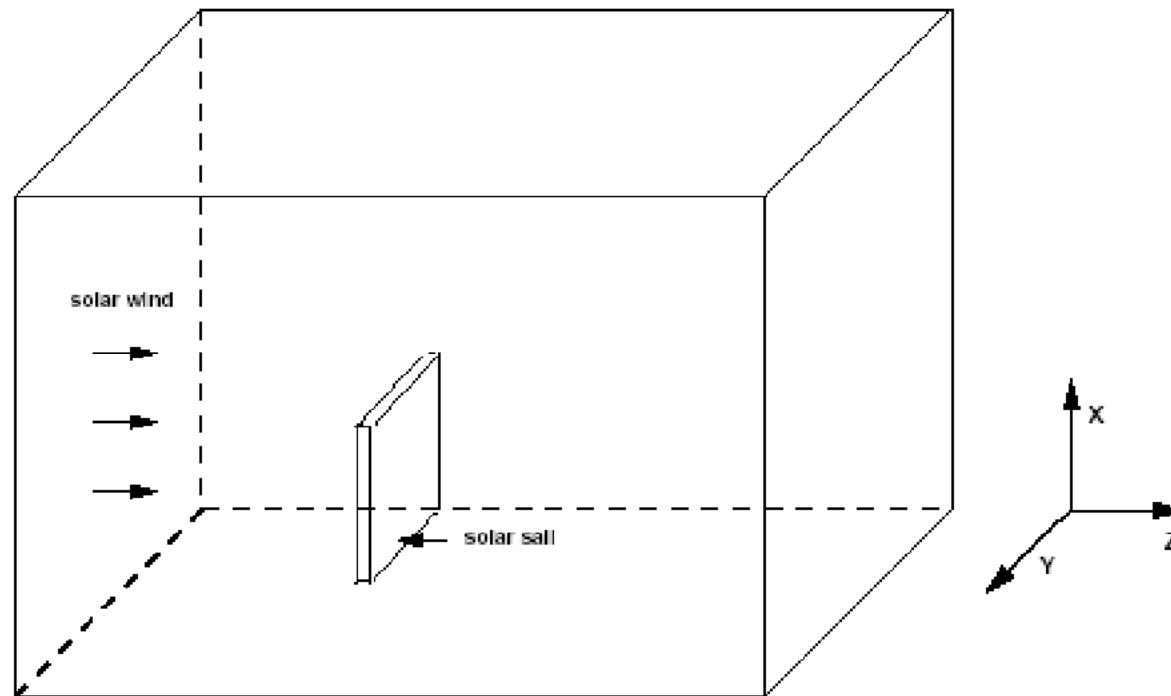
# Virginia Tech Plasma Flow Model



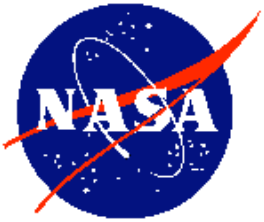




# *VT Model Simulation Setup*

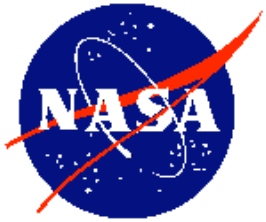


- 3-D simulations performed for quarter size Sail
- Solar Sail modeled as thin conducting plate with a potential
- Solar wind injected from upstream surface along z direction
- Solar wind modeled as particle protons and fluid electrons.

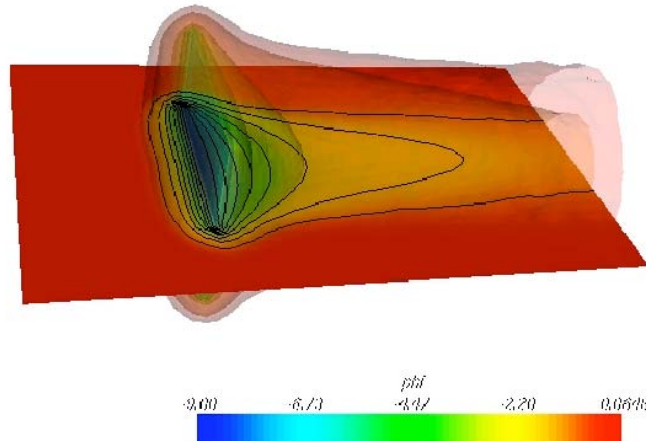


## *Model Assumptions*

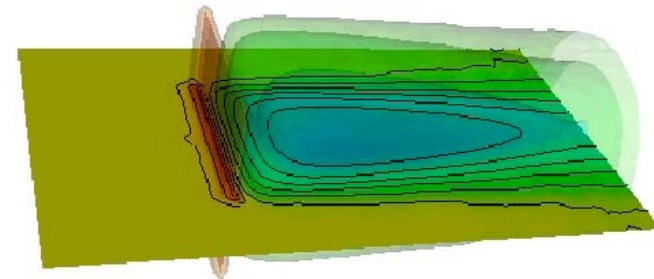
- **3-D, Electrostatic Particle-in-Cell (PIC) code**
- **Solar Wind protons treated as particles**
- **Solar Wind electrons treated as isothermal fluid (Boltzmann distributed)**
- **Electric field/particle trajectories solved self-consistently using dynamic alternating direction implicit (DADI) solver in 3-dimensions [Wang et al. (2001)]**



## VT PLASMA FLOW MODEL



A



B

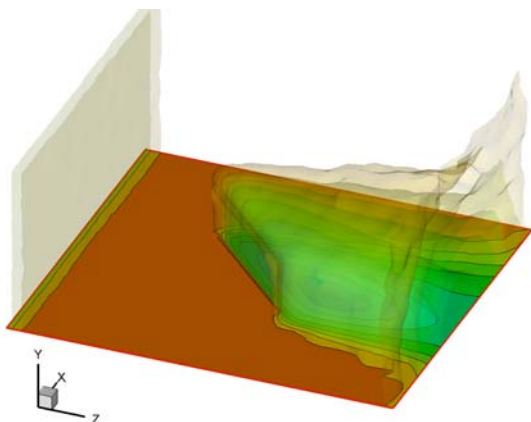
Parametric solar sail case studies. (a) Sail in the solar wind with the potentials normalized by  $0.25 T_e$  and (b) sail in the ionosphere for potentials normalized by  $-2.25 T_e$ .



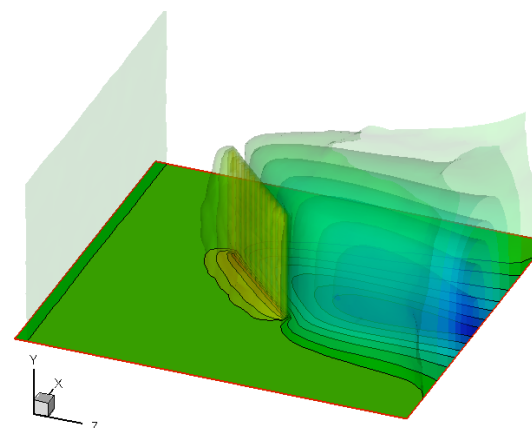
## SOLAR SAIL INTERACTIONS



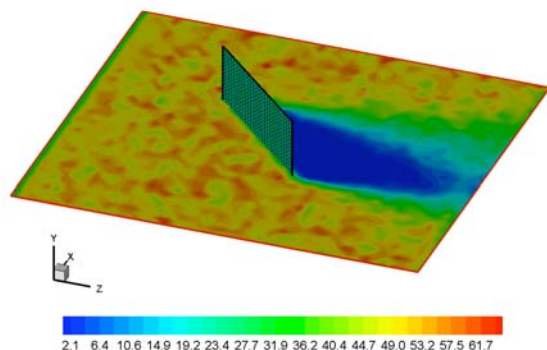
# VT PLASMA FLOW MODEL



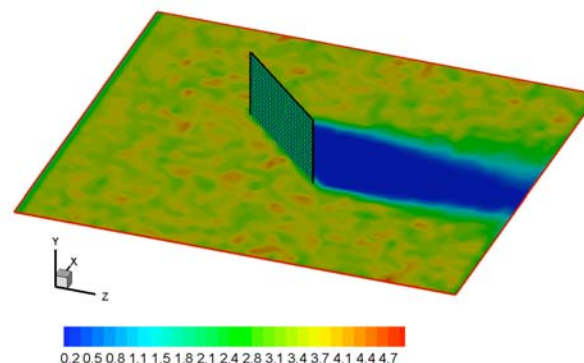
Potential contours predicted at 0.5 AU for 45°



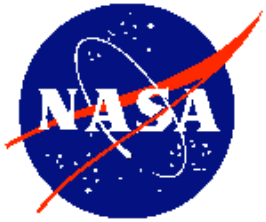
Potential contours predicted at 1.0 AU for 45°



Ion density contours predicted at 0.5 AU for 45°



Ion density contours predicted at 1.0 AU for 45°



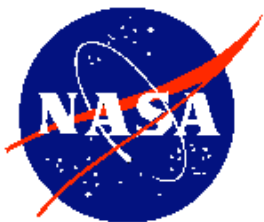
# *Summary*

- **Provided worst case and nominal environments for Solar Wind and Geosynch**
- **Currently evaluating computer models for estimating surface charging of Sails in the Solar Wind and Geosynch**
- **Will develop and document integrated procedure (“tool”) for using charging models and material properties to predict effects of Solar Wind and Geosynch on Sails**





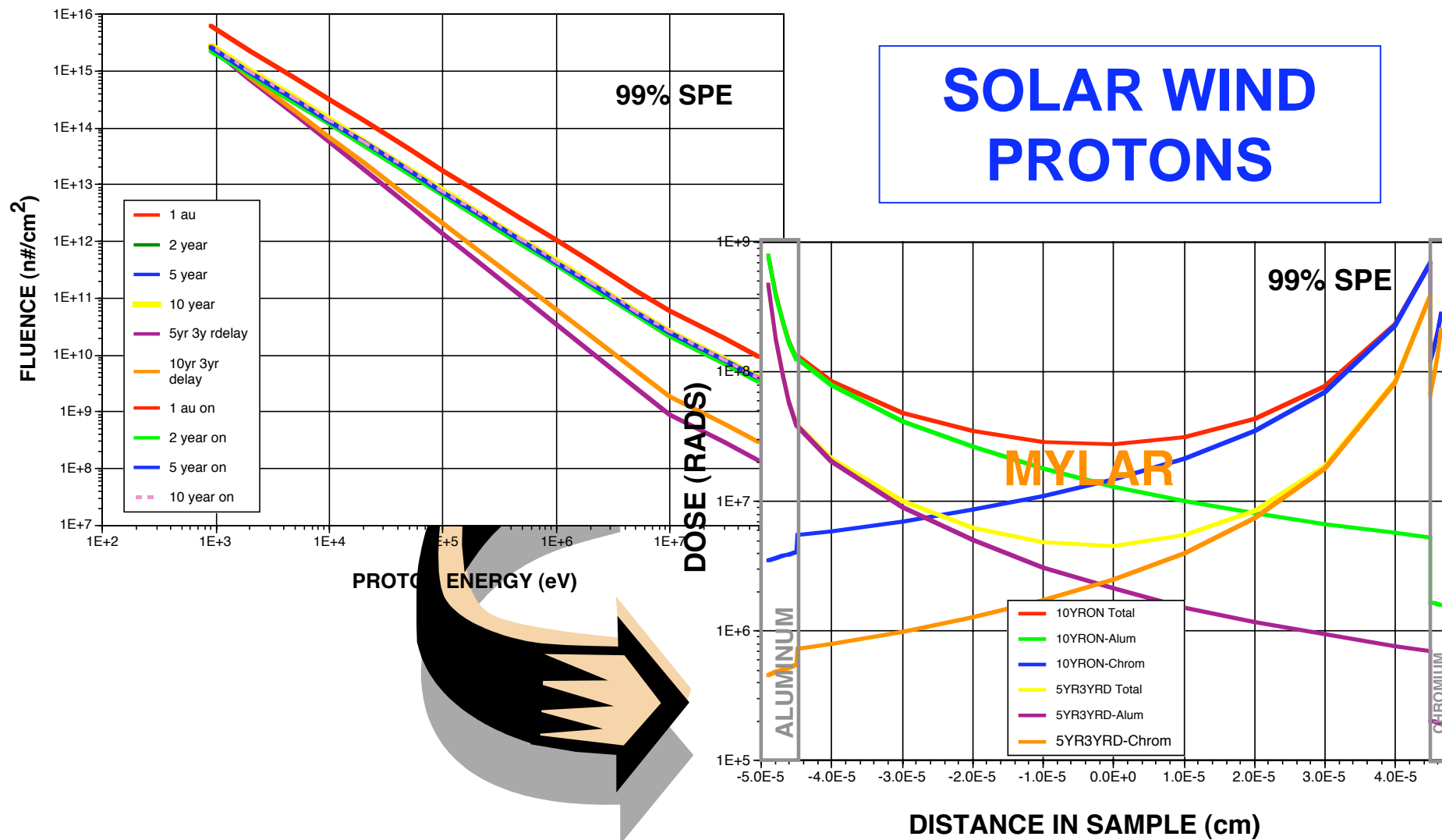
# BACKUP SLIDES



## SOLAR SAIL INTERACTIONS



# Dose Depth Curve for Al/Mylar--JPL



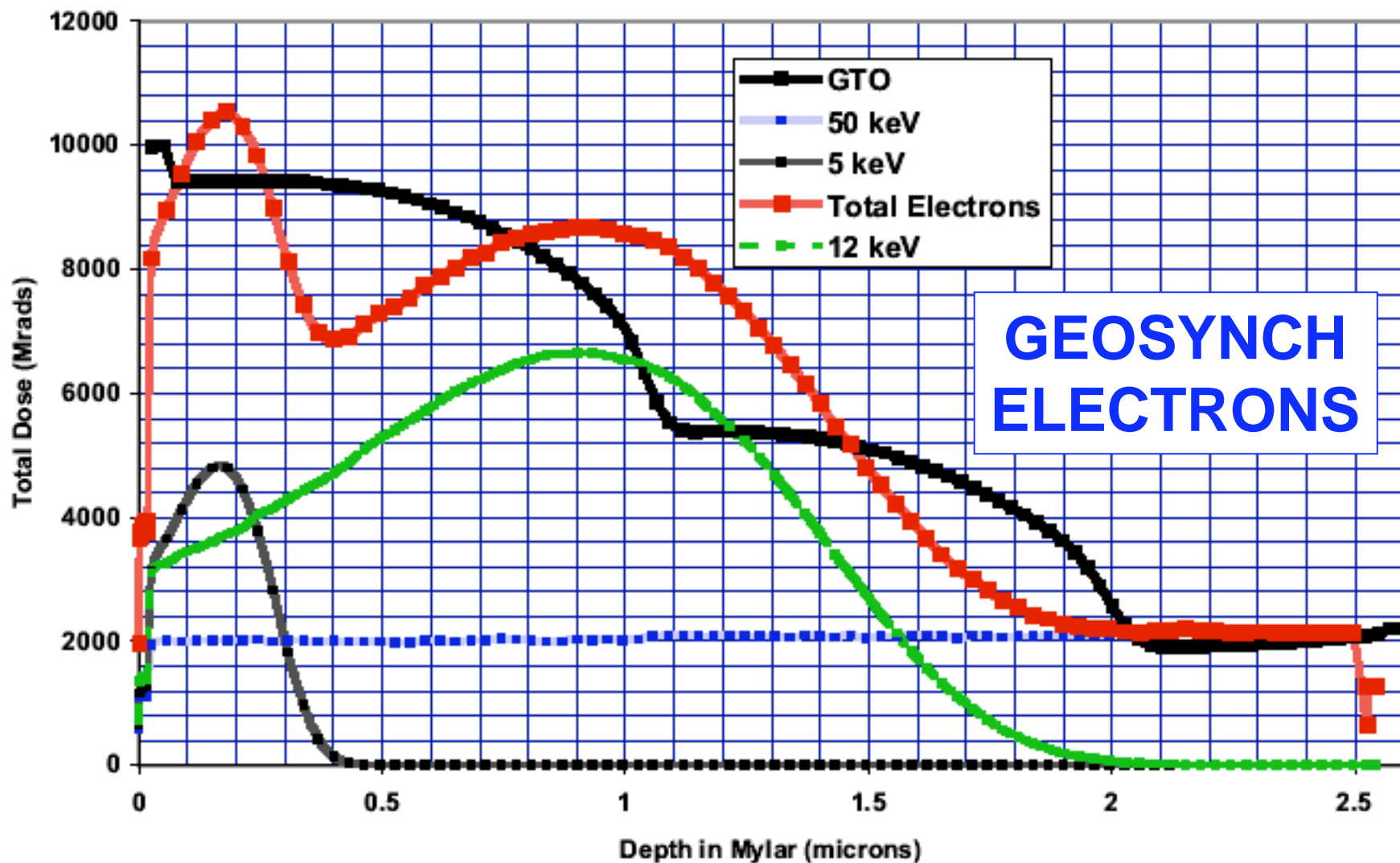


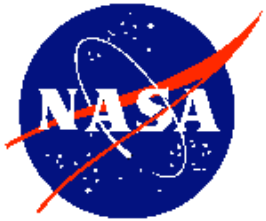
## SOLAR SAIL INTERACTIONS

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### *Dose Depth Curve for Al/Mylar--D. Edwards*





# *Solar Sail Model Tool/Procedure Development*

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## Goal:

- Create consistent methodology for calculating 3-dimensional sheaths and wakes around Solar Sails in Solar Wind and Geosynch orbits using NASCAP2K/VT charging codes. Use outputs from testing and modeling to develop integrated procedure for evaluating new materials for their charging and radiation properties and then predicting Sail response to Solar Wind and Geosynch environments.